

Appendix 4

EQUIVALENT PROCEDURES AND DEMONSTRATING
"NO ACOUSTICAL CHANGE" FOR PROPELLER-DRIVEN SMALL AIRPLANES AND
COMMUTER CATEGORY AIRPLANES1. Equivalent Procedures

Equivalent Procedures, as referred to in this AC, are aircraft measurement, flight test, analytical or evaluation methods that differ from the methods specified in the text of part 36 Appendices A and B, but yield essentially the same noise levels. Equivalent procedures must be approved by the FAA. Equivalent procedures provide some flexibility for the applicant in conducting noise certification, and may be approved for the convenience of an applicant in conducting measurements that are not strictly in accordance with the 14 CFR part 36 procedures, or when a departure from the specifics of part 36 is necessitated by field conditions.

The FAA's Office of Environment and Energy (AEE) must approve all new equivalent procedures. Subsequent use of previously approved equivalent procedures such as flight intercept typically do not need FAA approval.

2. Acoustical Changes

An acoustical change in the type design of an airplane is defined in 14 CFR section 21.93(b) as any voluntary change in the type design of an airplane which may *increase* its noise level; note that a change in design that *decreases* its noise level is not an acoustical change in terms of the rule. This definition in section 21.93(b) differs from an earlier definition that applied to propeller-driven small airplanes certificated under 14 CFR part 36 Appendix F. In the earlier definition, acoustical changes were restricted to (i) any change or removal of a muffler or other component of an exhaust system designed for noise control, or (ii) any change to an engine or propeller installation which would increase maximum continuous power or propeller tip speed.

The definition of acoustical change in section 21.93(b) for propeller-driven small airplanes and commuter category airplanes is more in line with that for other aircraft categories. For example, an increase in takeoff weight without any change in engine/propeller installation would not be considered an acoustical change under the earlier definition. Now it would be, since the reference height for noise level measurement would be lower with the increased weight, which would result in a higher noise level.

Section 36.9 defines the noise compliance requirements for propeller-driven small airplanes and commuter category airplanes for which an acoustical change approval is applied for under section 21.93(b). Section 36.9 recognizes two airplane categories: those that have previously been shown to comply with part 36, and those that have not. For the first group, any acoustical change must not increase noise levels beyond the limits stated in Part D of Appendix G. For the second group, noise levels may not exceed either these same limits, or "the noise level created prior to the change in type design, measured and corrected as prescribed in § 36.501 of this part," whichever is greater. Section

36.501(c) also requires that "compliance must be shown with noise levels as measured and prescribed in Parts B and C of Appendix G, or under approved equivalent procedures."

The FAA considers any change in type design that will increase the noise level by 0.1 dB or more an acoustical change. However, no acoustical change results as long as any change that can be expected to increase noise level is offset by other changes in design or performance that will decrease noise level in such a way that the sum of the changes does not increase the expected noise level by 0.1 dB. The purpose of this supplement is to examine methods for calculating changes in noise level introduced by common type design changes and methods for showing compensating noise level effects that will result in a demonstration of "no acoustical change."

3. Factors That Change Noise Level

Noise levels under Appendix G test procedures are affected by both the basic noise producing properties of the propeller/engine installation and by the takeoff and climb performance of the airplane. Regardless of what mechanical change is made to the airplane, noise levels can be expected to increase if any of the following conditions results from a type design change (without compensating changes):

- a. Decrease in the height of the airplane at the reference distance of 8200 feet (2500 m) from brake release;
- b. Increase in engine horsepower;
- c. Removal or alteration of exhaust mufflers;
- d. Increase in propeller helical tip Mach number;
- e. Increase in propeller tip thickness;
- f. Decrease in airplane climb path angle;
- g. Increase in airplane drag;
- i. Increase in inflow angle;
- j. Change in blade number.

Increases expected in the Appendix G noise levels caused by any of the above changes must be offset by a compensating change if "no acoustical change" is claimed, and an appropriate analysis must be provided. Removal of exhaust mufflers or other changes in the exhaust system may require some form of testing to determine the acoustical effect. Similarly, increasing propeller tip thickness, such as by cutting the tips off an existing propeller to decrease its diameter, may cause an increase in noise level (which might be offset by the decrease in the propeller rotational Mach number at the same rpm). In both the case of the altered exhaust system and that for the cut-down propeller, a simple comparison test, during which noise levels are measured for the modified and the unmodified airplanes utilizing flybys at the same height and airspeed, may be approved as a satisfactory equivalent test procedure.

Comparison tests are not generally cost saving methods since they may become as complex as a full part 36 Appendix G test.

4. Examples of Type Design Changes That May Affect Noise Levels

Typical applications for type design changes that require an evaluation of the effect of the change on noise levels include:

- a. Increase in takeoff weight without any change in engine or propeller installation.
- b. Change from a fixed pitch propeller to a variable pitch propeller.
- c. Change in propeller diameter.
- d. Change in number of blades.
- e. Increase in engine horsepower.
- f. Modification that increases drag without any change in engine or propeller installations. Examples include installation of external cargo containers, larger tires on fixed gear, or advertising light arrays.

In many cases, changes in noise level introduced by these modifications can be determined analytically by using existing data for the unmodified airplane, or by supplementing the existing data with additional performance information. Most requests for supplemental type certificates (STC) are made by applicants that do not have access to manufacturer's noise level data, even if these data exist. Since part 36 Appendix G applies to noise certification tests completed after December 1988, much of the existing fleet of small propeller airplanes do not have noise level data evaluated according to part 36 Appendix G. In order to obtain an STC, an applicant must demonstrate "no acoustical change" or conduct an entire Appendix G test. Several examples are given here of ways to demonstrate compliance using the adjustment factors described previously.

There are, however, some design changes which an applicant might argue that Appendix G compliance is not required, based on similarity to previously approved type certificates (TC) or STCs. Examples of this are older airplanes in a series where the series has several different engine sizes certified in the same basic airframe. Converting an airplane from one engine power to higher engine power by an applicant for an STC will require the applicant to do a noise analysis, possibly including noise measurements, even though the same engine/airframe combination exists in a production series. The reason for this is that the manufacturer is very unlikely to have demonstrated 14 CFR part 36 Appendix G compliance with any of his production airplanes. Even if the manufacturer has demonstrated compliance and the certificated noise level is published in an FAA Advisory Circular, the data used to demonstrate compliance, including the 90 percent confidence level for the certificated noise level, is proprietary to the manufacturer.

Before the adoption of Appendix G, certain changes to an airplane were accepted as "no acoustical change" by the FAA without any analysis. Two examples are the replacement of a two-blade propeller with a three-blade propeller, and an increase of less than 2 percent takeoff weight. For the reasons described below, these two types of changes are no longer accepted as "no acoustical change" unless the "no acoustical change" is substantiated by analysis and/or test data.

In the case of propeller replacements with increased number of blades, the change in noise generating mechanisms cannot be simply accounted for by tip Mach number and engine power corrections. Also, the increase in the number of propeller blades shifts the blade passage to higher frequency, which has a smaller A-weighting filter adjustment. In STC applications with propeller changes, the FAA may require a comprehensive "no acoustical change" analysis to account for the modified noise generation mechanisms, and the A-weighting filter effects or flyover tests have to be conducted.

Increasing the maximum certificated takeoff weight over the base airplane (or aerodynamic changes which increase drag of the aircraft such that its takeoff performance deteriorates) would cause it to fly at a lower height over the noise measurement location, which results in a higher noise level. An increase in takeoff weight without any change in engine/propeller performance would be an acoustical change unless the noise increase is offset by performance gains or reduction in airplane noise generation, any of which must be substantiated by analysis and/or test data. It is possible to show a "no acoustical change" condition analytically as given *Example 1* of this supplement, without actual field-testing.

4.1 Increase in Weight

For a change in airplane takeoff weight without any change in engine/propeller installation, the following factors influence the noise level under 14 CFR part 36 Appendix G procedures.

- a. As a reasonable approximation, the takeoff distance to a height of 50 feet is increased by a factor equal to the square of the ratio of the weight after the change to the weight before the change.
- b. The best-rate-of climb speed will increase essentially as the square root of the ratio of the weight before and after the change.
- c. The climb angle at the increased weight will be lower.

The noise level produced at the higher weight will be greater than at the lower weight because these items combine to generate a lower reference height. The increase in airspeed can also cause a modest change in the reference helical tip Mach number, which may increase noise level.

The incremental change in noise level, if nothing else is done, can be shown by an example. Note that the subscript "b" is used to denote the "before" conditions and the subscript "a" is used to denote the "after" condition.

The following examples are provided to give applicants guidance for "no acoustical change" analysis. The performance calculations used in the examples are for demonstration purposes only; they are not FAA approved performance calculation procedures. Any change in performance data (takeoff or

climb) that is to be utilized in the determination of "no acoustical change" must be published in the aircraft flight manual.

Example 1: Calculate the change in noise level expected if the weight of an airplane increases from 3,000 lbs to 3,200 lbs, without any other changes, given the following (note that all of the data given is readily available or is calculable from virtually all aircraft operations handbooks):

$$\begin{aligned} D_{50} &= 2220 \text{ ft} = \text{distance to 50 feet altitude} \\ V_y &= 90 \text{ kts} = \text{speed for best-rate-of climb} \\ R_c &= 970 \text{ ft/min} = \text{best rate of climb} \\ \gamma &= \sin^{-1}(R_c/V_y) \\ &= \sin^{-1}[970/(60 \cdot 1.688 \cdot 90)] = 6.11^\circ \\ &= \text{climb angle} \end{aligned} \quad \text{equation (1)}$$

$$\begin{aligned} h &= \tan(\gamma)(8200 - D_{50}) + 50 \\ &= \tan(6.11^\circ)(8200 - 2220) + 50 \\ &= 690 \text{ ft, reference altitude over the prescribed measurement location} \end{aligned} \quad \text{equation (2)}$$

$$\begin{aligned} D &= 84 \text{ in} = \text{propeller diameter} \\ \text{rpm} &= 2600 \text{ rpm} = \text{propeller speed} \\ T &= 59(^\circ\text{F}) - \text{lapse rate} \times h \\ &= 59(^\circ\text{F}) - 0.003566 \times 690 = 56.5^\circ\text{F air temperature at reference altitude} \end{aligned} \quad \text{equation (3)}$$

$$\begin{aligned} c &= 49.025 \times (T + 459.67)^{1/2} \\ &= 1113.8 \text{ ft/s} = \text{speed of sound at reference altitude} \end{aligned} \quad \text{equation (4)}$$

$$\begin{aligned} \Delta &= (1 - 0.0000068753 \times h)^{5.2561} \\ &= 0.99518 = \text{pressure ratio at reference altitude} \end{aligned} \quad \text{equation (5)}$$

$$\begin{aligned} \theta &= (T + 459.67) / (59(^\circ\text{F}) + 459.67) = 0.99518 \\ &= \text{temperature ratio at reference altitude} \end{aligned} \quad \text{equation (6)}$$

$$\sigma = \Delta / \theta = \text{density ratio} \quad \text{equation (7)}$$

$$\begin{aligned} V_{tas} &= V_y / \sigma^{1/2} \\ &= 90.9 \text{ knots} = \text{true airspeed of aircraft} \end{aligned} \quad \text{equation (8)}$$

$$\begin{aligned} M &= V_{tas}/c \\ &= 1.688 \cdot 90.9 / 1113.8 = 0.1378 \\ &= \text{aircraft Mach speed} \end{aligned} \quad \text{equation (9)}$$

$$\begin{aligned} M_R &= D \times \text{rpm} / (60 \times 12 \times c) = 0.8556 \\ &= \text{propeller rotational Mach number} \end{aligned} \quad \text{equation (10)}$$

$$\begin{aligned} M_h &= (M^2 + M_R^2)^{1/2} \\ &= 0.8666 = \text{helical tip Mach number} \end{aligned} \quad \text{equation (11)}$$

Step 1: Calculate the reference height for a weight of 3200 lbs.

- a. The takeoff distance before the change, $D_{50(b)}$, is 2220 ft. After the weight increase the takeoff distance is given by:

$$D_{50}(a) = 2220(3200/3000)^2 = 2526 \text{ ft} \quad \text{equation (12)}$$

b. The new best rate-of-climb speed at sea level, standard day, $V_y(a)$, is given by:

$$V_y(a) = 90(3200/3000)^{1/2} = 93.0 \text{ kts} \quad \text{equation (13)}$$

c. Calculating the climb angle at the increased weight can be done by several methods, depending upon the data available from the aircraft operations handbook or flight manual. Where handbook or manual data are not available, data such as climb rate or sink rate may be obtained by performing a limited amount of climb tests. Any such performance tests must be conducted with FAA approval.

Method 1: A general equation for calculating climb performance can be obtained if best rate-of-climb data are available in the aircraft operations handbook for different airplane weights. These data can be used to calculate an effective thrust during takeoff, and the effective ratio of drag to lift. For stable climb conditions at moderate climb angles where the cosine of the climb angle may be assumed to be essentially equal to unity, the sine of the climb angle γ , which is also the ratio of rate-of-climb to climb speed, is determined from:

$$\sin \gamma = R_C / (101.3 \cdot V_y) = F/W - C_D/C_L \quad \text{equation (14)}$$

where F is the thrust developed by the propeller, and C_D/C_L is the ratio of drag to lift coefficients. Thrust is the product of propeller efficiency and engine power, divided by airspeed, with appropriate unit conversions. If it is assumed that the ratio of propeller efficiency to airspeed is approximately constant for airspeeds used for best-rate-of climb, then it can be assumed that thrust remains approximately constant for a given horsepower rating for takeoff. By obtaining R_C and V_y for two different weights, two simultaneous equations are obtained using equation 14. These may then be solved for F and the ratio of C_D/C_L , since only the ratio is required.

In addition to the data for a weight of 3000 lbs, the manual gives a rate-of-climb of 1140 ft/min at 2700 lbs. The best rate-of-climb speed for a weight of 2700 lbs will be the speed for 3000 lbs times the square root of the ratio of the two weights, or 85.4 kts. Writing two equations with these values, and by subtracting one from the other, the effective thrust, F , is found to be 686 lbs, and the drag/lift coefficient ratio is 0.1222.

Substituting the values for thrust, drag/lift ratio, and airspeed for the desired weight of 3200 lbs yields climb angle of 5.29° . For a climb airspeed of 93.0 kts, the rate-of-climb is obtained as 868 ft/min.

Method 2: Rate of climb, R_C , in ft/min, is:

$$R_C = (33000\eta P)/W - R_S \quad \text{equation (15)}$$

where P is engine horsepower, η is propeller efficiency, W is airplane weight in pounds, and R_S is airplane power off sink rate in ft/min.

Some aircraft operations handbooks give a power off glide ratio and speed, from which a sink rate can be calculated. The sink rate calculated using these values is *not* the same as is obtained when operating at best rate-of-climb speed and propeller rpm. The best power off glide condition for an airplane with a variable pitch propeller is obtained with the propeller at low rpm (i.e. a blade pitch angle that provides minimum drag, and usually at an airspeed that is higher than that for best rate-of-climb. Note that in equation (14), if thrust is zero in glide, then the sine of the glide angle is just equal to the ratio of the drag to lift coefficients. For best glide distance this ratio will be lower than the ratio obtained during takeoff climb. For example, for the airplane in Example 1, the aircraft operations handbook states that the airplane will glide 1.7 nautical miles while losing 1000 ft in height, at an airspeed, V_γ , of 105 knots. The glide angle, γ_g , is calculated by observing that its tangent is given by the ratio of the height lost to the distance traveled. Thus:

$$\gamma_g = -\tan^{-1}[1000/(1.7 \cdot 6076.1)] = -5.53^\circ \quad \text{equation (16)}$$

In this mode of operation C_d/C_l is equal to the sine of 5.53° , or 0.0964. In the calculation above, it was found that C_d/C_l was 0.1222 for takeoff with the propeller operated at maximum rpm.

The rate of sink in takeoff configuration can be obtained by conducting glide tests at the speed for best rate-of-climb with the propeller at high rpm. The time required to lose a fixed altitude, 1000 ft or more, while holding constant airspeed, will give a sink rate that can be used in equation (15). At 90 kts and high rpm, the sink rate for the example airplane is approximately 1125 ft/m.

Propulsive efficiency, that is the product of propeller efficiency and installed power, can be calculated from equation (15) by using this sink rate, in conjunction with the manual value for climb rates at a given weight. Once these factors have been obtained, the climb rate at a different weight can be calculated, and this, coupled with the new climb speed, will allow the climb angle to be computed as in Example 1.

In Example 1 the best rate-of-climb was 970 ft/min at sea level at a weight of 3000 lbs. Substituting these values into equation (15), along with the sink rate of 1125 ft/min, gives a product of propeller efficiency and horsepower, for this airplane, of 190. With no change in horsepower or propeller efficiency, substituting these values in equation (15) gives an equation for rate-of-climb at any weight, W :

$$R_c = (6.285 \times 10^6 / W) - 1125 \text{ ft/m}$$

At a weight of 3200 lbs, the rate-of-climb becomes 839 ft/m. At an airspeed of 93 kts, the climb angle γ is given by:

$$\gamma = \sin^{-1}[839/(101.3 \cdot 93)] = 5.11^\circ$$

Method 3: An empirical expression for calculating the rate-of-climb, $R_c(2)$, at one weight, $W(2)$, when the rate-of-climb, $R_c(1)$, at a different weight, $W(1)$, is known is given by:

$$R_c(2) = R_c(1)[W(1)/W(2)]^{1.5} \quad \text{equation (17)}$$

Substituting 3000 lbs for W(1), 3200 lbs for W(2), and 970 ft/m for $R_C(1)$, $R_C(2)$ is calculated to be 880 ft/m. In turn, climb angle γ by this method is given by:

$$\gamma = \sin^{-1}[880/(101.3 \cdot 93)] = 5.36^\circ$$

- d. Reference height for the 3200 lbs takeoff weight can now be calculated with each of the three rate-of-climb values by using the equation:

$$h = 50 + (8200 - D_{50}) \cdot \tan \gamma$$

From the rate-of-climb of Method 1:

$$h = 50 + (8200 - 2526) \tan (5.29) = 575 \text{ ft}$$

From the rate-of-climb of Method 2:

$$h = 50 + (8200 - 2526) \tan (5.11) = 557 \text{ ft}$$

From the rate-of-climb of Method 3:

$$h = 50 + (8200 - 2526) \tan (5.36) = 582 \text{ ft}$$

The modest discrepancies among the three calculated values are related to the erroneous assumption that the ratio of propeller efficiency to airspeed is essentially constant. To be conservative, the lower value for h may be used in the analysis, or alternatively, the average of the three methods, 571 ft.

Step 2. Calculate reference Mach number.

- a. Speed of sound at height $h = 571 \text{ ft}$, from equations (3) and (4) is:

$$c = 1114.4 \text{ ft/s at } 571 \text{ ft above sea level}$$

- b. Square root of air density ratio at 571 ft is given by equations (5-7):

$$\sigma = 0.97954 / 0.99614 = 0.98334$$

- c. Best rate-of-climb speed of 93.0 kts at sea level becomes airspeed at 572 ft of:

$$V_{tas} = 93 / 0.98334^{1/2} = 93.8 \text{ kts}$$

- d. Airplane Mach number at 93.8 kts is:

$$M = (1.688 \cdot 93.8) / 1114.4 = 0.1421$$

- e. Propeller rotational Mach number is given by equation (9):

$$M_R = 0.8551$$

- f. Helical tip Mach number is given by the square root of the sum of the squares of the airplane and propeller rotational Mach numbers.

$$M_h = [(0.1421)^2 + (0.8551)^2]^{1/2} = 0.8668$$

Step 3. Reference horsepower remains essentially constant.

Step 4. Calculate the increment in noise level under 14 CFR part 36 Appendix G operating conditions when the airplane is operated at a weight of 3200 lbs instead of at 3000 lbs, without further changes.

- a. Increase in noise level due to decrease in height from 690 ft to 571 ft:

$$\Delta_h = 22 \cdot \log(690/571) = 1.81 \text{ dB}$$

- b. Increase in noise level due to increase in helical Mach number:

From Example 1, $M_h = 0.8666$.

$$\Delta_M = 150 \cdot \log(0.8668/0.8666) = 0.02 \text{ dB}$$

where the nominal value helical tip Mach number correction of 150 is assumed .

- c. Change in noise level due to change in climb angle:

In Example 1 the climb angle was 6.11° . Using the average climb angle obtained from the three methods described above, 5.25° . Tests conducted by FAA under controlled conditions in a wind tunnel show that for typical small propeller airplane, sound levels increase as climb angle increases due to the change in air-inflow angle to the propeller. On average an increase of 0.5 dB per degree increase of inflow angle was observed in the tests. Then, the change due to climb angle is given by

$$\Delta_\gamma = 0.5 (\gamma_a - \gamma_b) = 0.5 (5.25 - 6.11) = -0.43 \text{ dB} \quad \text{equation (18)}$$

- d. Total change in noise level:

The total change in noise level, ΔL , is the algebraic sum of the three adjustments.

$$\Delta L = 1.81 + 0.02 - 0.43 = 1.4 \text{ dB}$$

Clearly, a substantial acoustical change is created if the weight for this airplane is increased to 3200 lbs without any other change to the engine/ propeller installation or other operating conditions.

4.2 Change From Fixed to Variable Pitch Propeller

If no other change is made to the airplane, such as increasing horsepower, the primary effect of changing from a fixed to variable pitch propeller of the same diameter is a change in Mach number. Typically, fixed pitch propellers are designed to operate optimally under cruise conditions where the propeller is designed to reach its maximum continuous rated rpm. During climb at the speed for best

rate-of-climb the propeller cannot develop anywhere near its maximum rpm. Typically, takeoff rpm is approximately 85 percent of maximum rpm. For example a 150 hp engine having a maximum propeller rpm of 2700 will develop about 2300 rpm at takeoff. A 235 hp engine with a maximum rated rpm of 2575 typically develops about 2200 rpm in takeoff climb.

One of the primary reasons for changing from a fixed to variable pitch propeller is to shorten takeoff distance and to improve takeoff climb rate. An examination of aircraft operations handbooks for airplanes certified with both fixed and variable pitch propellers, at the same horsepower and takeoff weight, indicates the following nominal characteristics:

- a. Takeoff distances to a height of 50 ft with variable pitch propellers are approximately 88-90 percent of the distance required with a fixed pitch propeller.
- b. At the same takeoff weight and airspeed, the rate-of-climb with a variable pitch propeller is approximately 9-10 percent greater than with a fixed pitch propeller.

The incremental difference in noise level between an airplane equipped with a variable pitch propeller and a fixed pitch propeller can be estimated by using the same adjustment equations used before for height, Mach number, engine power, and climb angle.

Example 2: The aircraft operations handbook for a representative fixed gear airplane with a takeoff weight of 2900 lbs has the following performance data with fixed and variable pitch propellers:

	Fixed	Variable
Takeoff distance, ft	1510	1350
Rate-of-climb, ft/m	825	900
Climb speed, V_y , kts	87	87
Propeller dia, in	80	80
Propeller rpm in climb	2200	2575

Using the equations provided in Section 4.1 above, the following calculated quantities are obtained:

Reference height, ft	679	753
Climb angle, degrees	5.37	5.86
Speed of sound, ft/s	1113.9	1113.6
True airspeed, kts	87.9	88.0
Airplane Mach number	0.1332	0.1334
Rotational Mach number	0.6894	0.8072

Helical Mach number 0.7021 0.8181

The difference in engine horsepower developed with the two propellers in climb can be calculated by using equation (15) to write two equations for the rate-of-climb in terms of horsepower and sink rate, since the sink rate is the same and thus the only difference in rate-of-climb in the two situations is the actual propulsive power. For the fixed pitch case:

$$825 = (33000\eta P_f)/2900 - R_s$$

For the variable pitch case:

$$900 = (33000\eta P_v)/2900 - R_s$$

Subtracting the first equation from the second results in a difference of about 7 horsepower. The nominal maximum continuous power for the engine is 235.

All the information necessary to calculate the difference in noise levels between the two propeller installations is now available. In the nomenclature of the adjustment equations given previously, the fixed pitch propeller, the "before" conditions has the subscript "b" and the variable pitch propeller has the subscript "a". The difference in the noise levels for the two cases is the algebraic sum of the following adjustments:

- a. Decrease in noise level due to increase in reference height:

$$\Delta_h = 22 \cdot \log(679/753) = -0.99 \text{ dB}$$

- b. Increase in noise level due to increase in helical Mach number:

$$\Delta M = 150 \cdot \log(0.8181 / 0.7021) = 9.96 \text{ dB}$$

- c. Increase in noise level due to increase in engine power:

The rated maximum continuous power for the engine is 235 horsepower. If propeller efficiency for the two operating conditions is essentially the same, with an assumed value of 0.8, the incremental change in noise level is approximately:

$$\Delta P = 17 \cdot \log[(0.8)(235+7)/(0.8)(235)] = 0.22 \text{ dB}$$

- d. Increase in noise level due to increase in climb angle:

$$\Delta_\gamma = 0.5 \cdot (5.86 - 5.37) = 0.25 \text{ dB}$$

- e. Total change in noise level:

$$\Delta L = -0.99 + 9.96 + 0.22 + 0.25 = 9.44 \text{ dB}$$

Clearly, an acoustical change exists between the fixed and variable pitch propeller installations unless some other changes are made to the airplane. Note that this case clearly demonstrates a major difference between the older Appendix F test conditions and the current part 36 Appendix G. Under part 36 Appendix F, both planes would be flown at the same altitude, eliminating the height effect of item a. above. Since maximum continuous power in level flight would be used, it would be expected that the fixed pitch propeller would develop maximum rated rpm, the same as for the variable pitch propeller. Since they are of the same diameter, they would have the same helical Mach numbers, and the adjustment of item b above would be equal to zero. Finally, there is no climb angle difference to account for, so item c above would also be equal to zero. Under part 36 Appendix F, the fixed and variable pitch propeller installations would have the same noise level.

4.3 Change in Propeller Diameter

Calculating the effect on Appendix G noise level of changing propeller diameter without any other change in power or performance is a straightforward application of the following equation:

$$\Delta_M = k \cdot \log (M_a/M_b)$$

where k equals a constant dependent on the propeller design and Mach number range. A nominal value of 150 is permitted in § G36.201 if M_T is smaller than M_R (test and reference respectively).

Although a change in propeller diameter will usually also change performance, if it can be shown that no degradation in takeoff distance or climb performance is created, the airplane performance before the change can be stipulated as the performance after the change. It is clear that an increase in diameter, considered alone, will increase the noise level. It is sometimes desirable to increase propeller diameter to improve climb performance, sometimes at the sacrifice of some cruise capability. The increased noise level caused by the greater diameter can be offset by a reduction in rpm, if the resulting airplane performance is satisfactory. Where this method is used to show "no acoustical change," it may be necessary to perform takeoff and climb tests to verify performance. The following two examples illustrate the effect that changes in propeller diameter have on the noise level.

Example 3: The airplane in Examples 1 and 2 is normally equipped with a two-blade propeller having an 84 inch diameter. The same propulsive efficiency is claimed when using the same engine, same propeller rpm, if the propeller is replaced with a propeller of 80 inches diameter. For the same reference height and airplane speed, the difference in noise level between the two installations may be calculated as follows. In Examples 1 and 2, the airplane Mach number was 0.1378 and the propeller rotational Mach number was 0.8552 for an 84 inch diameter propeller. For the same altitude and rpm, the rotational Mach number is directly proportional to the propeller diameter, so the rotational Mach number for the 80 inch diameter propeller is 80/84 times 0.8556, or 0.8149. The corresponding helical Mach numbers after the change and before the change become 0.8265 and 0.8666. The noise level difference is:

$$\Delta_M = 150 \cdot \log(0.8265 / 0.8666) = -3.09 \text{ dB}$$

If the new propeller has three blades, which would cause a shift in the blade passage frequency, the above analysis would not be adequate to justify "no acoustical change". The analysis would have to

be extended to account for the noise delta caused by the ground reflections and A-weighting filter effects, or flyover tests would have to be conducted.

Example 4: An applicant wishes to replace an existing fixed pitch propeller with a diameter of 76 inches for a different pitched propeller with a diameter of 80 inches. The new propeller is designed to provide a somewhat shorter takeoff distance and better rate-of-climb for the airplane. The applicant does not want to go to the trouble of determining the improvement in takeoff distance or climb rate, and is willing to use the existing handbook data to determine reference height.

The applicant has demonstrated to the FAA that, in flight during reference climb conditions, his existing propeller develops 2300 rpm. He believes that, even with a modest limitation on climb rpm to negate the increase in noise level that a larger diameter propeller would normally generate, the larger propeller will still be advantageous. The rpm limitation that would have to be imposed for "no acoustical change" to result, assuming the reference height of 700 ft and true airspeed of 74 kts do not change, is determined as follows.

Since the airplane climb speed remains the same, the helical Mach number will be the same if the rotational Mach numbers for the two propellers are held constant. The actual reference height and airspeeds are not relevant to this determination. It is not even necessary to calculate the actual Mach numbers, since the rotational Mach numbers will be the same if the products of propeller diameter and rpm remain constant for the two cases. For the original 76 inch propeller, the product is 76 times 2300 or 174,800. The rpm limitation with an 80 inch propeller is therefore 174,800 divided by 80, or 2185 rpm. If this rpm gives satisfactory takeoff and climb performance, limiting climb rpm to 2185 will result in no acoustical change when the larger propeller is installed.

4.4 Change in Engine Power

Increasing the size of an engine without changing the takeoff weight of an airplane will change the Appendix G noise level. If no change in performance were involved, the level would increase by 17 times the logarithm of the ratio of the increased horsepower to the original horsepower. However, clearly a change in performance does take place. Takeoff distance is shortened, and climb rate is increased. Often, but not always, a propeller change is also made. If the increase in performance offsets the effect on noise level of the change in engine horsepower, no acoustical change occurs. The following example illustrates the required analysis.

Example 5: The airplane in Example 1 is originally equipped with an engine rated at 225 horsepower at 2600 rpm. The desired installation is for an engine rated at 250 horsepower at 2650 rpm. The same 84 inch two-blade propeller is used in each case. The acoustical effect of this change is evaluated as follows.

Step 1. If propeller efficiency remains the same, takeoff distance varies inversely with engine power and directly as the square of takeoff weight. The takeoff distance to 50 ft height after the increase in horsepower, $D_{50}(a)$, without any weight increase, is the original takeoff distance, $D_{50}(b)$, times the ratio of the original horsepower to the increased horsepower:

$$D_{50}(a) = D_{50}(b) \cdot P(b)/P(a) \text{ ft}$$

In this example:

$$D_{50}(a) = 2220(225)/(250) = 1998 \text{ ft}$$

Step 2. From equation (15), rate-of-climb for a given airplane configuration is directly proportional to the ratio of engine power to airplane weight, minus the power off sink rate. The constant of proportionality is the unit conversion factor of 33,000 times the propeller efficiency. In Example 1, the product of propeller horsepower developed in climb is less than the rated horsepower due to installation effects and air density less than at sea level. It can be assumed that the same ratio of losses will apply to a slightly higher rated horsepower engine. Assuming these losses cancel each other out, the apparent propeller efficiency for Example 1 can be stated as the propulsive efficiency, 190, divided by the rated horsepower, 225, for an apparent efficiency of 0.844. Equation (15) can then be used to determine the rate-of-climb at the increased horsepower:

$$R_c(a) = (33000)(0.844)(250)/3000 - 1125 = 1197 \text{ ft/m}$$

Step 3. Climb angle is given by:

$$\gamma = \sin^{-1} [R_c / (1.688 \cdot 60 \cdot V_y)]$$

$$\gamma_a = \sin^{-1} [1197 / (101.3)(90)] = 7.55^\circ$$

Step 4. The reference height after the change, H_a , is:

$$H_a = 50 + (8200 - 1998) \tan(7.55) = 872 \text{ ft}$$

Step 5. Determine reference helical Mach number:

a. At 871 ft the speed of sound is:

$$c = 1113.2 \text{ ft/s}$$

True airspeed is calibrated airspeed divided by the square root of the density ratio:

$$\sigma = 0.97472$$

b. Best rate-of-climb speed of 90 kts at sea level becomes a true airspeed at 871 ft of:

$$V_{tas} = 90 / 0.97472^{1/2} = 91.2 \text{ kts}$$

c. Airplane Mach number at 91.2 kts is:

$$M = (1.688 \cdot 91.2) / 1113.2 = 0.1383$$

d. Propeller rotational Mach number is:

$$M_R = 0.8725$$

- e. Helical tip Mach number is:

$$M_h = [(0.1383)^2 + (0.8725)^2]^{1/2} = 0.8834$$

Step 6. Reference horsepower is now 250.

Step 7. Calculate the increment in noise level under 14 CFR part 36 Appendix G operating conditions:

- a. Change in noise level due to increase in height:

From Example 1, $H_b = 690$ ft, and from above $H_a = 872$ ft.

$$\Delta_h = 22 \cdot \log(690/872) = -2.24 \text{ dB}$$

- b. Increase in noise level due to increase in helical Mach number:

From Example 2, $M_h = 0.8666$:

$$\Delta_M = 150 \cdot \log(.8834/0.8666) = 1.25 \text{ dB}$$

- c. Increase in noise level due to increase in horsepower:

$$\Delta_P = 17 \cdot \log(250/225) = 0.78 \text{ dB}$$

- d. Change in noise level due to change in climb angle:

In Example 1 the climb angle was 6.11 degrees. From equation (18):

$$\Delta_\gamma = 0.5 \cdot (7.55 - 6.11) = 0.72 \text{ dB}$$

- e. Total change in noise level:

The total change in noise level, ΔL , is the algebraic sum of the four adjustments.

$$\Delta L = -2.24 + 1.25 + 0.78 + 0.72 = 0.51 \text{ dB}$$

The change in noise level due to an increase in horsepower, in this example, is not offset by the effect of improved takeoff performance, resulting in an "acoustical change" of 0.5 decibel. In order to become a "no acoustical change" situation, some change in rating should take place. A small reduction in allowable takeoff rpm might be reasonable. Several iterations of the above calculations might be necessary to determine the optimum conditions.

4.5 Increase in Drag With No Other Changes

Any modification to an airplane that increases its drag during takeoff and initial climb will increase the Appendix G noise level unless other changes are also introduced. If takeoff distance is increased, or rate-of-climb decreased, or both, the reference height will decrease. The change in level can be

calculated from the adjustment equations provided previously if the change in performance can be determined. If an applicant wants to show compliance with the noise regulation via the "no acoustical change" method, he will probably have to conduct takeoff distance and climb tests. If it looks as though the proposed modification will increase drag sufficiently to make a measurable performance change, then an offsetting change will be required. The amounts of increase or decrease in noise level involved can be calculated by the methods use in the previous examples.

4.6 Acoustical Effects of Combined Changes

Many proposed airplane modifications involve several changes. Examples are replacing an engine and fixed pitch propeller with a higher power engine and a variable pitch propeller, or increasing engine power and takeoff weight at the same time. The acoustical consequences of these combined effects can be calculated by combining the methods used in the examples. The sequence for calculating these effects is as follows:

- a. Determine the effect changes in takeoff distance and rate-of-climb will have on reference height.
- b. Determine the effect of helical Mach number caused by any changes in airplane speed, propeller rotational speed, or change in speed of sound because of change in reference height.
- c. Determine the effect of any changes in engine power.
- d. Determine any change in noise level due to change in airplane climb angle.
- e. Obtain the algebraic sum of the four incremental changes in sound level.
- f. If the sum is greater than zero, there are two choices:

Conduct Appendix G tests as described in the regulation; or,

Evaluate different operating conditions to obtain an incremental noise level that is not greater than that of the original airplane. This may be accomplished by derating the engine, reducing fuel/payload, and/or limiting maximum takeoff rpm. One or a combination of these modifications may be iterated until a negative noise increment is obtained by the methods used in the examples. The cost of not performing an Appendix G noise test should be balanced against the loss of airplane performance or takeoff weight limitations during the lifetime of operation.